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ON THE

INFLUENCE OF THE SOLAR RADIATIONS

ON THE

VITAL POWERS OF PLANTS

GROWING UNDER

DIFFERENT ATMOSPHERIC CONDITIONS.

PART II.

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On the Influence of the Solar Radiations on the Vital Powers of Plants growing under different Atmospheric Conditions.—Part II. *By* J. H. Gladstone, *Ph.D., F.R.S.*

Since I laid before the British Association my former Report, some of the experiments there detailed have been repeated, and the investigation has been pursued further in the same direction. I have the honour now to present the results which have been obtained.

The experiments about to be described were conducted, not as before at Stockwell, but in Tavistock Square, London. The locality was not quite so favourable to the growth of plants, but they had always the advantage (unless otherwise stated) of standing on tables at the windows of a large upper room having a south-east aspect, so that they obtained the full benefit of the morning and noonday sun. The apartment was never artificially heated, but in the winter time it must have been a few degrees higher in temperature than the external atmosphere.

The coloured bell-glasses described in the previous Report were made use of. I am now able to give a more accurate description of what solar rays were actually transmitted by them. The effects of the different glasses on the prismatic spectrum were as follows:—

Colourless glass. No perceptible difference from the normal spectrum.

Yellow glass. The red rays were cut off, but the line C was just visible in the orange-coloured region. The yellow and green portions of the spectrum were quite natural, except perhaps that they were rather more uniform in colour than usual; the blue was rather bright above the double line F, but there was very little illumination in the portion more refracted, and the violet rays were quite unseen. The lines D, E, *b*, and F were very visible.

Red glass. The spectrum consisted of two luminous spaces, separated by a broad band of perfect darkness. The one was of a red and orange colour, commencing between B and C, and apparently cut off by the dark line D. The other was faintly illuminated with an olive-green tint, commencing about the most intensely yellow part of the ordinary spectrum, and continuing to about *b* (which was barely visible), and then passing into a lilac hue, which gradually faded off, till it became imperceptible perhaps a little below the lines F.

Blue glass. The spectrum had a very singular appearance, consisting of several distinct luminous bands. First there was a reddish band of considerable brilliancy, occupying a space beyond that of the least refrangible portion of the visible spectrum. This was separated by a dark space from a very narrow but bright band somewhere near the line B. Its colour was very different from any of those of the normal spectrum, but perhaps it approached nearest to the orange. Then, after another dark space, came a bright yellow band of greater width, just above the line D, which, however, was not itself perceptible. The whole yellow portion of the spectrum was cut off, and there was no illumination till about midway between E and *b*, where a bright green suddenly appeared. This passed into a pale green, where there was very little illumination, but not perfect darkness, till at about F an intense blue appeared, continuing through the region of the violet, to the end of the most refrangible portion of the spectrum. The lines *b*, F, and G were very distinct, as well as some about *d* and H.

This analysis of the light transmitted by the various glasses, confirms the description previously given of their character, namely, that "The blue glass cuts off by far the greater portion of the luminous rays, but admits the

chemical rays freely; it may also be considered as interfering much with the transmission of heat. The red glass, on the contrary, freely admits the calorific influence, but stops the chemical, whilst, like the blue, it diminishes greatly the luminous. The yellow again scarcely decreases the illuminating power of light, but almost destroys its chemical action."

The series of experiments on hyacinths, which was described in the last Report, was repeated with additional attention to the effects of partial or complete darkness. The large colourless, blue, red, and yellow bell-glasses were employed, together with a partially obscured colourless shade, and a partially obscured yellow shade; and another experiment was instituted under a glass shade placed in a large box, so that the light was completely excluded, except when for a few moments the lid might be removed for the purpose of observing the progress of the experiment. As in the preceding experiment, the bulbs were all of the same description, of a healthy appearance, and of about the same size. After being weighed, they were placed as before on the top of colourless glasses, filled with pure water, and covered with the large bell-jars. In this case the jars were themselves placed upon the perforated boards, with the arrangement of tarlatane, &c., mentioned in the previous paper. The experiments were commenced on December 10th; each of them was successful; the results accorded in some points with those of the former occasion, but in other respects there was considerable discrepancy. The experiments made in partial or complete obscurity were perhaps the most instructive.

Rootlets began to appear immediately under the dark shade, and on December 26th, that is, after sixteen days, they were found to be $1\frac{1}{2}$ inch in length. They grew rapidly, and were very numerous. They were thin and long, and appeared to have little strength. Under the obscured colourless and obscured yellow glasses, the rootlets also began to grow quickly, becoming three-quarters of an inch long in a fortnight's time; while under the blue and colourless glass exposed to the full power of the light, the rootlets did not so quickly attain any length, and in the same space of time there was scarcely anything observable under the red or yellow glass. The roots continued to grow under the obscured glasses until the beginning of February, but they arrived more rapidly at maturity under the influence of the white and blue light. Under the red shade the roots never attained any considerable length, but they were stout and strong. Under the yellow shade there was scarcely any growth below the bulb until near the end of January, when a few long straggling roots made their appearance. This is very accordant with the effect that was observed during the previous season to be produced by the coloured glasses. This shows that the development of the root takes place most rapidly in the absence of all solar radiations; that partial obscurity is also favourable; that the less refrangible rays of the spectrum had especial power to retard their growth, and that the luminous and calorific rays had peculiar actions of their own.

As to the leaves, little appearance of growth was observable in any of the hyacinths till December 26th, when those under the colourless and blue glasses began to shoot; that under the red glass followed very soon, while those under the yellow and the partially and wholly obscured glasses gave no sign for about three weeks longer. The leaves grew most rapidly in the blue light. The following comparisons of the length of the leaves under the various luminous influences may be interesting. They were taken on the 13th and 21st of February, when all the plants were in vigorous growth, but not one of them had flowered, and on March 22nd, when the plants had attained their full maturity.

	February 13.	February 21.	March 22.
Under the colourless glass	4 inches	6 inches	11 inches
„ blue „	6 „	8 „	14 „
„ red „	3 „	5 „	11 „
„ yellow „	2 „	3 „	8 „
„ obscured colourless glass	3 „	3½ „	10 „
„ obscured yellow „	3 „	3½ „	12 „
„ dark glass	3 „	4 „	10 „

The flower-stalk very nearly kept pace with the leaves. There was a greater difference in the periods at which the petals opened than in the former series of experiments; those under the blue and colourless glasses took the lead, and those under the partially obscured glasses were the last. They opened for the most part during the last days of February. Under the red shade two flowers grew, but they were thin and straggling: the same was the character of the plant that grew in the dark. There were two flower-stalks under the partially obscured colourless glass; they were never developed, however, but were found at the end of March losing their colour and becoming rotten. The experiments were terminated on March 22nd, excepting the two under the partially obscured glasses, which were allowed to continue till the 30th. The respective lengths of the flower-stalks were then,—

Under the colourless glass....................	13	inches.
„ blue „	13	„
„ red „	12·5	„
„ yellow „	12	„
„ obscured colourless glass	4	„
„ obscured yellow „	10	„
„ dark „	13	„

The hyacinths having been removed from the water in which their roots had been immersed, were suffered to dry in the open air of the room for twenty-four hours, and were then weighed.

	Primary weight of bulb.	Fully developed plant.	Actual increase.
Under the colourless glass	936 grs.	1494 grs.	558 grs.
„ blue „	862 „	1472 „	610 „
„ red „	856 „	1438 „	582 „
„ yellow „	1008 „	1406 „	398 „
„ obscured colourless glass	873 „	1591 „	718 „
„ obscured yellow „	872 „	1556 „	684 „
„ dark glass	763 „	1205 „	442 „

If, instead of observing the actual increase of weight, we compare the original weight of the bulb with that of the fully developed plant, we obtain the following proportions:—

Under the colourless glass as	1000 : 1596.
„ blue „	1000 : 1708.
„ red „	1000 : 1680.
„ yellow „	1000 : 1395.
„ obscured colourless glass as	1000 : 1822.
„ obscured yellow „	1000 : 1784.
„ dark „	1000 : 1579.

This increase in weight in the growing hyacinth is due to the fixation of water, and not to the decomposition of carbonic acid in the atmosphere; at least a smaller bulb which was placed under a colourless shade, and cut off from the external atmosphere by the edges of the glass dipping into water, grew and flowered perfectly well; and when removed from the shade on March 22nd, and dried as the others were, it gave the following weight:—

Primary weight of bulb.	Fully developed plant.	Actual increase.
625 grs.	1167 grs.	542 grs.

or as 1000 : 1867,—

a larger proportional increase of weight than in any of the other experiments, the actual increase being about the same as that of the other plant which grew under the colourless glass.

The leaves that grew in the dark were perfectly etiolated, excepting just at the tips, where they showed the normal green colour gradually shading off as it descended. The leaves that appeared in the experiments with the obscured glasses, were somewhat lighter in tint than those growing where the direct radiance of the sun could find access. The character of the light, under which the flowers were grown, did not affect their colour at all in the way that might have been expected. They were all, as on the former occasion, of an equally deep purple; even that which grew in complete darkness exhibited the same depth of colour in all the petals, excepting a few of the lower ones. The purple flower under the colourless glass when fading turned to red; and this was also the case under the blue and yellow glasses; but the flower under the red glass showed no trace of red colour, even when it had quite shrivelled up, nor was there any such change in the intense purple that appeared where light was excluded.

In such experiments as those just detailed, it is difficult to separate what might be the effect of adventitious circumstances from the genuine effect of the diversity of light. However, we may safely remark in the experiment which was conducted in perfect obscurity—the rapid and abundant growth of thin rootlets, the general healthiness of the plant, the non-formation of chlorophyll, but the production of the colouring matter of the flower, not altered in its subsequent fading. The two experiments performed in partial obscurity appeared as closely alike as possible, until the last week, when one of the plants died. The fact that the chemical rays were cut off from one of them, made no apparent difference. Their backwardness, as compared with the other flowers, was probably owing to their having been placed in a position which was somewhat colder than that of those which received the full light of the sun. The effects of obscurity were observable in them in a modified manner, and they both absorbed much more water than the other plants did. The effect of the red glass in interfering with the length of the roots, and in producing a badly developed plant, was observed both in this and in the former series of experiments. Its power of preventing the reddening of the faded flower is remarkable. The effect of the yellow glass in causing the rootlets to be few and straggling, and in diminishing the absorption of water, was also noticed in both instances. The blue glass appeared to favour the development of the hyacinth.

That the green colouring matter of leaves requires the action of light for its production, has long been universally admitted, and Dr. Daubeny has shown that it depends on the luminous ray. From analogy, and from a few observations by Davy, Senebier, and others, the same has been assumed to hold good in respect to the colours of flowers, but the purple hyacinth bears other witness, and should induce us to doubt this too hasty conclusion.

A number of experiments on germination were made during the spring.

The seeds experimented on were those of the wheat and the pea; and in every case both were employed, in order that if there should be a different effect of light on the monocotyledonous and dicotyledonous plants, it might be seen. Seeds of familiar plants and of great commercial importance were chosen, as it was supposed a greater degree of interest would naturally attach to experiments on them, and it might happen that some observations of value to the agriculturist might be made.

The first series of experiments was made in common air, under the seven various influences of coloured light and obscurity which have been described in treating of the hyacinths. The coloured shades were arranged before the windows, as described above, and they dipped into plates of water, so that throughout the experiments they were filled with an unchanged atmosphere, saturated with moisture. Twelve grains of wheat and twelve peas were taken for each separate experiment, and their weight was noted while they were still dry. They were placed on bricks within the glass shades, the bricks standing in the water, so that they were always damp. Another arrangement was made, similar to that just described in every particular, except that the seeds were in the open air of the room, without any cover.

The experiments were commenced on April 21st. The following is a table of the weather, and of the temperature taken in the shade at midday during the time that the various experiments with peas and wheat continued:—

April 22.	cloudy		May 15.	fine	69°
„ 23.	do.		„ 16.	variable	65
„ 24.	do.		„ 17.	fine	66
„ 25.	variable		„ 18.	cloudy and wet	64
„ 26.	do.	60°	„ 19.	fine	66
„ 27.	wet	57	„ 20.	do.	67
„ 28.	variable	56	„ 21.	....	...
„ 29.	do.	56	„ 22.	cloudy and wet	64
„ 30.	....	...	„ 23.	fine	65
May 1.	wet	55	„ 24.	variable	63
„ 2.	variable	55	„ 25.	fine	66
„ 3.	do.	59	„ 26.	do.	67
„ 4.	fine	61	„ 27.	wet	63
„ 5.	variable	63	„ 28.	....	...
„ 6.	cloudy	60	„ 29.	wet	63
„ 7.	....	56	„ 30.	do.	63
„ 8.	variable	...	„ 31.	fine, but cloudy	65
„ 9.	wet	60	June 1.	fine	66
„ 10.	fine	58	„ 2.	wet	63
„ 11.	cloudy	62	„ 3.	fine	65
„ 12.	fine	60	„ 4.	....	...
„ 13.	cloudy	64	„ 5.	cloudy	63
„ 14.	....	65	„ 6.	do.	63

We shall first consider the growth of the wheat; afterwards that of the peas; and then compare the two.

On April 26th the corn-seeds were found just beginning to burst under all the seven glasses, those under the obscured yellow being the most advanced. Further growth was visible the following day under that glass, and also under the obscured colourless, and the yellow, though the plume did not appear in any case till the 29th. On May 1st the radicles under the colourless and blue glasses were of considerable length, but those under the obscured colourless and the red were longer, while the longest were under the yellow glass. On April 29th plumes appeared under the red and obscured colourless glasses, and in the dark. They appeared two days later

under the colourless and the blue, while the seeds under the obscured yellow had an unhealthy look. On the 4th of May long etiolated leaflets were found in the dark; under both obscured glasses the wheat had also shot up long leaves; under the red and yellow glasses there were plumes of 1 or 2 inches in length; while under the colourless and blue they only reached half an inch. The wheat-plants under the colourless glass then began to grow more rapidly, and soon gained the advantage of those under the blue, and still more of those under the red. On the 8th they measured 3 inches, while those that had grown in the dark measured 6.

On the 12th the wheat-plants were more fully examined, and drawings of them were made. It was then found that under the colourless glass ten of the twelve seeds had grown. They presented very uniformly the appearance given in Plate IV. fig. 1,—leaves erect, of a full green colour, from 4 to 5 inches in height, roots long and thin, five in number, taking firm hold of the brick. They had no side rootlets, but were fringed with hairs. Under the blue glass, the wheat appeared like that under the colourless, but smaller. Under the red, only four plants grew like fig. 1, and they were not so regular in form, size, or general aspect as those under the colourless glass. Four others had grown somewhat like fig. 2, where there was this peculiarity,—the green stalk had been unable to burst the transparent membranous sheath, and had forced itself out in a kind of loop, at that part where the sheath sprung out of the seed. The roots were generally flaccid. Under the yellow glass, the radicles were so strong, and bent so decidedly downwards, that they raised the seed completely on end: they were thickly covered with hairs. The stalks were short and strong, and generally bent in the manner represented in fig. 3. Under the obscured colourless glass only seven seeds had germinated: they were all like fig. 4. The leaves were of a pale green colour, and had not succeeded in bursting the membranous sheath; the roots were very long. Under the obscured yellow glass, the plants were of a greener colour than the preceding; six of them were like fig. 3, excepting that the leaves were very much taller, perhaps 7 inches high. In the dark all the plants were weak, and of a very pale green colour, almost yellow; the radicles had many rootlets branching out from them; four were like fig. 5; two others were smaller and had second leaves, while other two were very short in the leaves.

After this, the plants under the colourless glass continued to grow healthily: the hairs along the roots became very long and thick, and on the 22nd of May, ramifications of the rootlets began to appear. The plants under the blue did not continue so healthy, nor did those under the red. Under the yellow glass, both the upper plant and the roots continued to grow. Under the obscured yellow glass and in the dark, the plants also continued growing. On the 26th, a more full examination and fresh drawings were made. Under the colourless glass there were ten wheat plants like fig. 6, generally 8 or 10 inches in height. Under the blue glass there were several very thin weak plants, only about 2 inches high. Under the red, the utmost development was to the extent of fig. 7, in the case of three plants. The rest that were growing had not succeeded in breaking the membranous sheath, but were contorted in their efforts to escape. Under the yellow, three plants had grown like those under the colourless glass; three others were not so fully developed, while the remaining four had not germinated. Under the obscured colourless glass, the wheat had not grown since May 12th. Under the obscured yellow, I found six plants like fig. 8. In the dark, the plants had grown much as under the obscured yellow glass, but they were still longer, weaker, and paler in colour.

On June 5th, the experiments were stopped. The plants under the colourless glass were healthy in every respect, and were of a better green than any of the others. Under the red glass, one of the plants was found to have shot up several small leaflets outside the transparent sheath, which it had been unable to pierce.

The following table shows the number of seeds of wheat which had put forth roots, and the average length of the principal roots; and also the number of seeds from which plants had grown, together with the average length of the principal leaves.

	Roots.		Leaves.	
	No. of plants.	Length.	No. of plants.	Length.
Colourless	10	2·5 inches	10	10 inches
Blue	6	0·75 „	6	4 „
Red	8	3·5 „	4	4 „
Yellow	7	2 „	6	9 „
Obscured colourless	6	3·5 „	3	2 „
Obscured yellow	{ 6 2	0·75 „ 2·5 „ }	7	8 „
Dark	7	3 „	6	13 „

The plants were removed from the bricks, spread out on the table, and allowed to dry in the air for eighteen hours. The following table shows the weight of those which had grown under each of the various conditions of light. The original weight of the twelve corn-seeds was in each instance 8 grains, giving as the average weight of each seed 0·66 gr.

	No. of plants which had germinated.	Weight.	Average weight of each.	Average increase upon original weight.
Colourless	10	31 grs.	3·1 grs.	2·4 grs.
Blue	6	4 „	0·66 „	0 „
Red	8	4·5 „	0·56 „	−0·1 „
Yellow	7	8 „	1·1 „	0·4 „
Obscured colourless	6	4 „	0·66 „	0 „
Obscured yellow	7	10 „	1·4 „	0·7 „
Dark	7	9 „	1·3 „	0·6 „

The increase in weight of the plants which had grown under the colourless, the dark, and the yellow glasses, was due, of course, to the fixation of water, for there was no supply of carbonic acid from the air, and the quantity of substance which the roots could absorb from the bricks must have been very trifling.

The comparative experiment in which the seeds were exposed to the open air of the room did not come to anything. Not one of the seeds succeeded even in bursting the tunic, doubtless because the dry atmosphere prevented their ever retaining sufficient moisture.

The presence of soil about the germinating seeds, or a constant change of air, would probably have modified these results; yet the conditions observed in this series of experiments were thought necessary, in order to have the full effect of the different sorts of light about the seeds themselves, for a soil necessarily produces partial, if not total obscurity. The deprivation of other sources of carbon, beyond the cotyledons of the seed itself, also answered certain purposes. On examining the results, the following conclusions may be drawn, as far as wheat is concerned growing under the conditions of the

experiment. The absence of the chemical rays favours the first growth of rootlets, and the presence of the luminous rays does not impede it. Afterwards the opposite effect takes place; the roots are stopped in their development by the yellow ray much more than by all the rays of the spectrum in combination. The red or calorific ray is on the whole the most favourable to the growth of the roots, even more so than the complete absence of all solar radiations. The shooting forth of the plume is also favoured by the withdrawal of the chemical rays, especially just at first; but the full and healthy development of leaves requires all the rays of the spectrum, the luminous being particularly necessary. Several other peculiarities may be noted; for instance, the downward tendency of the roots under the pure luminous influence; the comparatively greater development and strength of the membranous sheath under the calorific agency; and the late but abundant growth of side-rootlets, where all the solar radiations were admitted.

The results of the experiments on wheat recorded in the previous Report, where there was the presence of soil and change of air, appear to indicate still more clearly the beneficial character of the luminous emanations, for the plants under the yellow shade were found even to excel those which had grown in white light, while, as in the experiment just detailed, the cutting off of the luminous ray by the deep blue glass militated greatly against the health of the plants. The protection of the rootlets from the yellow ray may be fairly considered an advantage, but a proper series of experiments on wheat-seeds surrounded by earth is still a desideratum.

We have now to consider the growth of the *peas* under the different solar influences. It has been already stated that twelve peas soaked in water were placed on the bricks along with the wheat seeds, on April 21st. On the 24th they were found to be swollen and beginning to burst. The seeds under the yellow, obscured yellow, and obscured colourless glasses, were the more rapid in their first development. On the 29th, the plumes began to appear under the obscured colourless, yellow, and red shades, and two days afterwards under the blue and colourless. The plants under the obscured yellow glass appeared very unhealthy. The radicles grew astonishingly under the yellow glass, and became very long under the red and obscured colourless. On May 8th, the plants in complete or partial obscurity were found to be several inches high; under the red, 2 inches; under the yellow, not quite so much; while even on the 11th, the plants under the blue had only just developed themselves, and under the colourless glass only one seed had put forth a stalk, and that was but half an inch in length.

On the 12th they were more fully examined, and drawings were made. Under the colourless glass, the peas resembled fig. 1, Plate V. the plume only in the first stage of development, the principal root short and thick, with short and thick secondary rootlets, all fringed with hairs. Under the blue, the peas were in a somewhat more advanced stage, like fig. 2. Under the red, ten plants had grown somewhat like fig. 3,—roots straggling, stalk bending towards the light, with many leaflets of a deep green colour. The plants under the yellow glass were characterized by enormous roots, as shown in fig. 4, which turned away from the light in a very marked way. Nine of those under the obscured colourless had the appearance presented by fig. 5,—long roots, long succulent weak stalks, and pale green leaflets. Under the obscured yellow, the plants appeared for the most part like fig. 4, but with smaller roots, though two of them, which were nearest the light, had grown with a stalk like that represented in fig. 5. In the dark, six of the peas had grown like fig. 6,—roots irregular, having few side-rootlets, stalks succulent, but tolerably erect, bearing yellow leaflets. The plants in

the red light continued to grow healthily, some being 6 inches high on the 15th; under the yellow and obscured yellow, they also grew healthily; under the obscured colourless, the stalks were found on the 22nd no longer capable of supporting themselves. The stalks in the dark were at the same time erect, and 10 inches in length. On the 26th, the seeds under the colourless glass were found to have made scarcely any advance since the 12th. Under the blue, one had grown tall and healthy, but the rest were very small. Under the red, the plants were growing healthily as on the 12th, but some of them had attained the height of 9 inches, and bore three or four secondary branches. Those under the yellow had grown, but did not appear healthy. Under the obscured colourless glass, the plants had grown since the 12th about as much as might have been expected from the time, but they were very weak. Under the obscured yellow glass there were two very similar to, and nearly as large as, those under the obscured colourless. Six others were of the same character, but much smaller; the roots were very short. The plants in the dark had also grown since the 12th.

On June 5th the experiments were discontinued. The longest pea-plant under the colourless glass was then only 1·75 inch in length; the secondary rootlets were remarkably short and thick. The plants under the blue appeared the most healthy; those under the yellow, whether in full light or obscured, showed considerable inclination to send out lateral branches. The stems of the plants in the dark were white, the leaflets were canary-yellow; those which had grown in partial obscurity were also much etiolated. One of the peas under the obscured yellow had produced a triple stem, and so had one of those under the obscured colourless glass, as drawn in fig. 7.

The average length of the roots and stalks of those peas which had germinated under the different solar influences is given in the annexed table:—

	Tap roots.		Stalks.	
	No. of plants.	Length.	No. of plants.	Length.
Colourless	10	1 inch	10	1 inch
Blue	{10 2	2 „ 5 „}	12	7 „ „
Red	11	3·5 „	11	6 „
Yellow	{7 4	1·5 „ 6·5 „}	10	6·5 „ „
Obscured colourless	10	2 * „	9	6 „
Obscured yellow	10	1·5 „	10	5 „
Dark	12	3 * „	12	14·5 „

The plants were removed from the bricks and allowed to dry in the air for eighteen hours. The following table shows the increase of weight which had taken place in them during their growth:—

	Original weight of 12 peas.	No. of plants which had germinated.	Weight.	Average weights of each.	Average increase of original weight.
Colourless	33 grs.	10	54 grs.	5·4 grs.	2·7 grs.
Blue	34·5 „	12	73 „	6·1 „	3·2 „
Red	30 „	11	47 „	4·3 „	1·8 „
Yellow	34 „	11	72 „	6·5 „	3·7 „
Obscured colourless	35·5 „	10	83 „	8·3 „	5·4 „
Obscured yellow	31·5 „	10	85 „	8·5 „	5·9 „
Dark	31·5 „	12	150 „	12·5 „	9·9 „

* Very various.

It being thought that the disproportionate weight of the plants which had grown in the dark might be partially owing to their not having become thoroughly air-dried in eighteen hours, on account of their succulent character, they were exposed in the same manner for forty-eight hours. Their weight was then reduced to 66 grains, whilst those grown under the obscured colourless (succulent as they were) lost in the same time only 14 grains; and those under the obscured yellow appeared rather to have gained weight.

The increase in weight in these instances must be attributed, as in the case of the wheat, to the absorption of water, and it seems to be in almost reverse ratio to the healthiness of the plant; for those under the red, which had the best appearance at first, showed by far the smallest increase in weight; and those under the blue, which were afterwards better looking, had not increased greatly.

In the comparative experiment made without any glass shade, one pea began to germinate on May 23rd; this was shortly followed by two others, but only one of the three grew to any size. When measured on June 6th, its root was found to be only 0·75 inch long; its stalk had attained a length of 4·5 inches; its leaflets were deep green, appearing as healthy as, if not healthier than, any under the glass shades, and when removed from all moisture for eighteen hours, it weighed 5·5 grains, showing an increase of 2·7 grains on its original weight.

On examining these results we are led to draw the following conclusions, as far as peas are concerned, growing under the conditions of the experiment. The cutting off of the chemical rays favours the first germination of the seed, and this appears to be the principal, if not the only advantage of the darkness obtained by burying the seeds in the soil. The development of roots also requires the absence of the chemical ray; yet it does not go on to the greatest extent when all the solar influences are excluded, but is favoured rather than otherwise by heat and luminosity. The first development of the plume also proceeds best under the same circumstances; yet these are not the conditions which produce a healthy plant: if all the solar radiations be withdrawn, whether entirely or only to a great extent, the plants absorb much water and grow very tall, without developing secondary branches or many leaves. The whole force of these radiations, on the contrary, prevents or greatly impedes the growth of these plants under the circumstances of the experiment. As peas grow commonly in the full sunshine, it would be interesting to observe whether the negative result obtained arose from the absence of soil about the roots, from excessive moisture, or from some other cause. The experiment, however, affords us no data for determining this question. The chemical force is the most antagonistic to the growth of the pea, and luminosity also militates against it: the heating rays are favourable; but let the plant be fairly established, and those radiations which are comparatively speaking devoid of light, but replete with chemical power, are the most suited to the production of a healthy growth. The influences which facilitate rapid growth are diametrically opposed to healthy development. It should be borne in mind, however, that these observations relate only to a very early stage of the plant, and teach us nothing respecting the full-grown pea, or the evolution of the flower or fructification.

If we compare the effect of the various solar radiations upon the germination of wheat with the effect produced upon that of peas, we are struck with the great diversity between them. This was particularly apparent during the progress of the experiment. The colourless and the red glasses happened to stand side by side on the table, and it was curious to notice under the former glass a tall and vigorous crop of corn-plants with a mere matting of

stunted roots from the peas, while under the other a thick crop of green spreading plants arose from the germinating peas, but the wheat-plants were few, straggling, and unhealthy in appearance. When, however, we come to look more closely into the phænomena, we see certain points of resemblance. In both cases the cutting off of the chemical ray facilitates in a marked manner the process of germination, and that both in reference to the protrusion of the radicles and the evolution of the plume. The unnaturally tall growth of the stem, and the poor development of leaves in darkness, more or less complete, is also common to both these specimens of the monocotyledonous and dicotyledonous plant. In both cases too, the yellow ray exerted a repellent influence upon the roots, giving the wheat a downward and the pea roots a lateral impulse.

The object of employing a partially obscured yellow glass in these experiments, was to decide if possible the question which has been asked, Does yellow light stop germination by some specific action or merely by the excess of light? Contrary to the experience of some others, who, I believe, have experimented on seeds covered with soil, and on other plants than those employed by me, the yellow light did not interfere at all with germination, in the experiments just described. In the case of both plants, indeed, it decidedly facilitated the early development of both the root and the plume. That the yellow ray, however, has a specific action of its own, is proved by the most cursory glance at the facts already recorded; the yellow and the obscured yellow give quite different results from those of any of the other glasses.

The diversity between the effect of the same qualities of light upon the growth of the wheat and the pea leads us to suspect at once any generalisations affecting other plants which may be drawn from the observed influence of light upon one particular plant, especially, of course, when they are of different orders. This will account for some of the diversity of statement made by previous experimenters in these fields.

The subject may be, however, further elucidated by referring to some of these. Dr. Draper, in his elaborate investigation of the forces which exert a controling influence on the growth of plants, records a series of experiments on peas. He placed them just after they had begun to grow in blue, red, and yellow light, and also in the dark, and in the open air. His observations were confined to the third and fourteenth days. At the former period he found that under the red the plant had attained 4·5 times its original size, and had produced double the number of leaves; under the blue, three times its original height, with also double the number of leaves. In the dark there was about the same increase of altitude, while in the open air only twice the original height had been attained, and there were no fresh leaves; and under the yellow light, a still smaller advance had been made. On the fourteenth day he found all his pea-plants green, though varying a little in the character of the colour, except those which had been placed in the dark, which were of a pale whitish yellow, the plants vigorous, thirteen times their original height, but with no fresh leaves. On the whole, then, as far as Dr. Draper's experiment goes, it is in accordance with my results.

M. Senebier describes an experiment performed by him on lettuce-seeds sown in little cups and placed respectively in the open air in full light of day, in darkness, and under glass vessels filled with colourless, yellow, red, and violet fluids. "Observing then the effects produced by the different portions of light which were thus permitted to act, he found that the plants illuminated by the yellow rays grew most rapidly in height; next, those in the violet rays; afterwards those in the red rays. The plants which grew in light transmitted through water were still smaller and approached in size to

those which flourished in the open air, while those in perfect darkness attained the greatest height of all. These last plants perished on the eighth day, and those in the yellow light on the ninth day, while all the others continued to vegetate. At the end of about five weeks, the plants growing under the red vessel were 4 inches and 9 lines in height; under the violet vessel 3 inches and 3 lines; under the water vessel 2 inches and 10 lines, and 1 inch and 3 lines in the open air. With respect to the general appearance of the plants, the leaves of those which grew in red light were smaller and less smooth than those of the plants in violet light, or than the leaves of the plants confined under water, or than the leaves of those which grew in the open air. As to colour, the leaves exposed to yellow light were at first green and afterwards became yellow; those in red light appeared green and preserved a tinge of that colour; those in violet light were quite green and their colour augmented with their age; while those raised in obscurity possessed no verdure at all." These experiments were repeated on French beans with nearly similar results, but beyond the observation that "in proportion as the plants grew in height, in different kinds of light, the number and size of their leaves diminished," his attention appears to have been directed only to the question of colour*.

Besides the experiments already detailed in this Report, and those on wheat and *Malope trifida* described in my former one, I have a few other observations on the effect of various qualities of light on the growth of plants from the seed, which it may be worth while briefly to record. They were made on the *Collinsia bicolor* of the florists, and *Mignonette*.

Seeds of the *Collinsia* were sown in garden mould in glasses, and placed under the colourless, blue, yellow, red, and darkened shades, on a table before a window which had a N.W. aspect. The perforated boards were used for supporting the glass covers. The experiment was commenced on the 6th of July in last year. On the 9th it was found that germination had taken place under each glass except the yellow, where no plant grew until the 14th. Under the colourless glass, the plants grew and flourished till the beginning of August, when they all faded and died. Under the blue and red glasses they grew well for awhile, but began to droop by the 26th of July. Those under the darkened glass existed rather longer, but they were tall and scraggy, and the leaves did not fairly open. Only three plants germinated under the yellow shade; they were all unhealthy and died before the 26th. On August 4th, seeds were sown afresh under each glass. Much the same order of growth was observed.

On October 12th, a hundred seeds of Mignonette were sown in each of seven glasses filled with garden mould. They were placed about a third of an inch below the surface. Six of the glasses were covered respectively with the colourless, blue, red, yellow, obscured colourless, and obscured yellow shades, and the seventh was placed in a dark closet. It should be observed that the closet was rather warmer than the room. The Mignonette seeds began first to germinate in the dark, then under the blue; then, after the lapse of a few days, they appeared under the red, and colourless, and the obscured colourless glasses. The yellow ray long retarded, and very nearly prevented their germination. Those in the dark were tall, thin, and yellow; they all died about November 1st; the others soon followed, excepting one plant under the colourless glass, which was found still alive with four green leaves on December 10th.

The investigations of many experimenters have shown that oxygen is

* From Ellis's "Farther Inquiries," &c.

necessary in the germination of seeds. The explanation given is that that element is required for instituting the action that converts the fecula of the cotyledon into sugar. It is unquestionable, that in the majority of cases, plants after the first stage of their growth require a certain supply of carbonic acid, by the decomposition of which they obtain carbon, setting free oxygen. My brother and I have shown that plants will exist well for a considerable time in an atmosphere devoid of oxygen, for instance in nitrogen, hydrogen, coal-gas, or carbonic oxide. In order to see the effects of all these atmospheric conditions on the germination of wheat and peas, the following experiments were made during the latter part of May and the beginning of June.

Six wheat-seeds and six peas were placed on folds of linen floating on mercury, and covered with a colourless glass jar having a capacity of about 20 cubic inches. The linen preserved the seeds from the mercury, and was kept wet by the introduction of a small quantity of water. The jar was full of atmospheric air, and was placed on the table before the window having a S.E. aspect. After a couple of days or so the peas germinated, and shortly afterwards the wheat. They grew for about a week, and retained a healthy appearance much longer. The experiment was twice performed with similar results, and showed that the arrangement was applicable to the proposed experiments.

A precisely similar arrangement was made in a jar containing 29 cubic inches of hydrogen gas, and having in it a tube containing pyrogallate of potash, so as to absorb any trace of oxygen which might be accidentally present in the gas, or might be evolved from the seeds themselves. In four days the swollen peas had begun to burst. They put forth short radicles, but no plume, and in about a week afterwards they were all decaying. The wheat showed no appearance whatever of germination. This experiment was twice performed with the same result.

Another such arrangement was made in a jar filled with carbonic acid. Not the slightest appearance was indicated by either the wheat or the peas. They decayed, becoming soft and swollen, and emitted a most offensive smell on the removal of the jar.

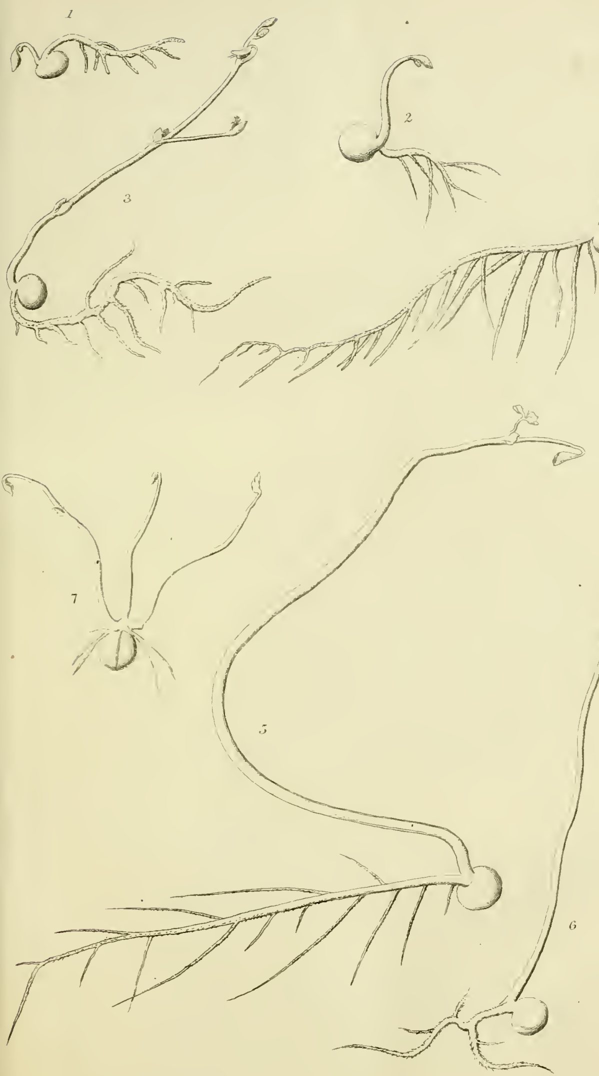
The same was done in a jar filled with common air, and containing a solution of caustic potash in a small capsule, so as to remove any carbonic acid which might be given off by the seeds. In about three days both the wheat and the peas had begun to burst; four out of the six of each continued to grow for about six days, and remained healthy afterwards. The removal of the carbonic acid, then, did not affect the germination. I subsequently found that in this experiment I had almost exactly repeated one of Mr. Ellis's in his 'Inquiry into the changes produced on atmospheric air by the germination of seeds,' &c. He employed peas, and satisfied himself that all the oxygen in the jar had been absorbed by the germinating plants.

The effect of oxygen on the germination of wheat and peas under the influence of the different solar radiations was also tried. The small coloured glasses, having a capacity of 172 to 177 cubic inches, were employed, and the experiments were conducted like those under the coloured shades which have been already detailed. The seeds were placed on the bricks on May 2nd. On the 8th, both the wheat and the peas had burst under the colourless glass, but they soon became mouldy, and before the end of the month they were quite dead. The seeds under the yellow glass ran much the same course; but those under the blue glass, though they did not burst till the 11th, grew well, and by the 26th two of the wheat plants had attained a height of 4 or 5 inches. The experiment was discontinued on June 5th. The plants

were removed from the brick for desiccation, and on the following day the five of the wheat which had germinated were found to weigh 8 grains, giving an average of 1·6 grain for each, or an increase of 0·9 grain on the original weight. All the six peas had germinated and weighed 26 grains, giving an average of 4·3 grains for each, or an increase of 1·6 grain on the original weight.

Thus far I have proceeded in the investigation. Many interesting inquiries naturally suggest themselves; some have been already alluded to, for instance, the influence of light upon the colours of flowers; the amount of exclusion of light effected by the soil; the different condition of solar influences required by wheat or by peas at later periods of their growth; and the extension of the observations to other seeds. Other questions might be raised, such as,—What character of light promotes best the absorption of oxygen in germination? At what period in the growth of a plant does oxygen become unnecessary? Is oxygen requisite for the full development of a bulbous-rooted plant? Does carbonic acid act specifically in the prevention of germination, or merely by the exclusion of oxygen? How far does the rapid development of a plant in an early stage interfere with its healthy growth at a later period?

J.W. Lowry fc.



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